



Performance Limits for GRS Electrostatic Sensing and Forcing

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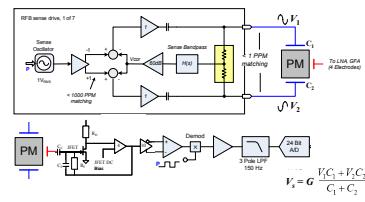
Stanford University



Engineering model electrostatic sensing and forcing electronics developed for LISA GRS Pathfinder obtain measured displacement sensitivity $\sim 1 \text{ nm}/\text{rtHz}$ to $f \leq 0.1 \text{ mHz}$ with $< 10^{-6} \text{ s}^{-1}$ calculated stiffness, and precision forcing to $a_{\max} = 2 \times 10^{-9} \text{ m/s}^2$ with 20-bit step resolution and noise level $\Delta a < 5 \times 10^{-15} \text{ m/s}^2$. DC bias control for electrode work function compensation achieves $8 \mu\text{V}/\sqrt{\text{Hz}}$ stability with $< 2 \text{ mV}$ step resolution over $\pm 50 \text{ mV}$, while high-authority forcing acceleration $a_{\max} = 2 \times 10^{-7} \text{ m/s}^2$ for proof-mass initialization and rapid charge measurement when needed is provided by $> 30 \text{ Vdc}$ fields on-demand. Results allow to update the GRS noise tree terms for electrostatic sensing, forcing, and nulling.

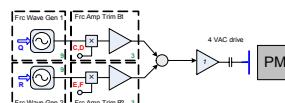
AC Precision Sensing

- Drive applies mirror symmetric signals
- JFET front-end senses residual vs. x
- Selectable null-detector mode reduces stiffness during off-center operation
- Performance governed by output ratio tracking resistor and JFET input noise



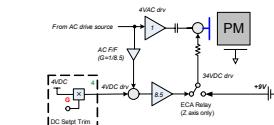
AC Precision Forcing

- Dual ~kHz carriers, one for steady-state mass-attraction compensation along x , the other for transverse/angular control
- 20-bit composite DAC over 0 to $\sim 2\text{VRms}$ provides 2 microvolt rms step resolution
- FPGA updates all DACs simultaneously to maintain self-consistent force vector

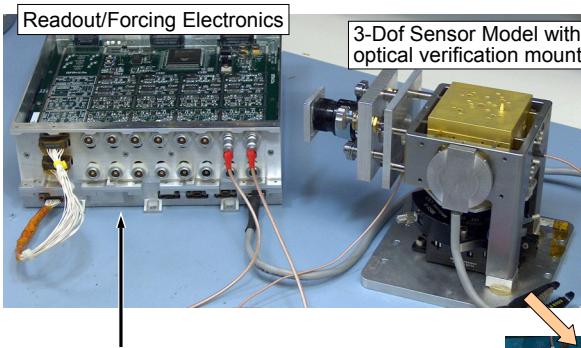


DC Forcing and Nulling

- Bootstrap for $\pm 30\text{Vdc}$ at low power
- 16-bit DAC for $\sim 1\text{mV}$ step resolution
- LTZ1000-based ultra-stable reference
- Input supply voltage may be reduced when only $\pm 50\text{mV}$ range is needed
- Electrostatic caging (Pathfinder only)

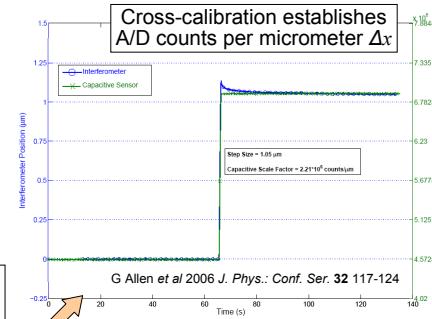
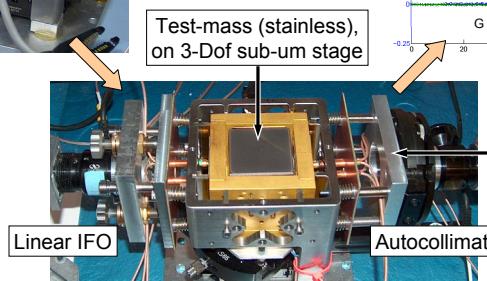


Electronics Engineering Model, 3-Dof Sensor Model, and Electrostatic/Optical Cross-Calibration



Readout/Forcing Electronics Performance:

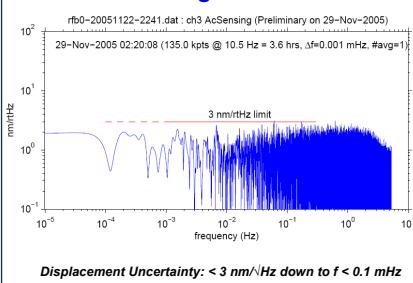
- AC Sensing: $3 \text{ nm}/\sqrt{\text{Hz}}$ down to $f < 0.1 \text{ mHz}$
- AC Forcing: $2 \times 10^{-9} \text{ m/s}^2$, at $\Delta a < 5 \times 10^{-15} \text{ m/s}^2$
- DC Forcing: $2 \times 10^{-7} \text{ m/s}^2$, at 3.9mm by $\pm 30\text{Vdc}$
- DC Nulling: $\pm 50\text{mV}$, $\Delta V < 2\text{mV}$, $\delta V \sim 8 \mu\text{V}/\sqrt{\text{Hz}}$
- All components have space-rated equivalents



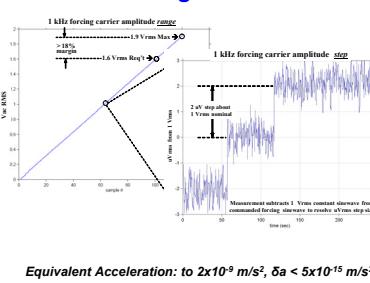
GRS Facsimile 3DOF Test Article
Accurate 1-4-2 electrode pattern
(x , y , θ) stage for canonical motion
Linear IFO and Autocollimator
for displacement calibration
Thermal stability to $< 400 \mu\text{K}/\sqrt{\text{Hz}}$

S Higuchi et al 2006 J. Phys.: Conf. Ser. 32 125-131

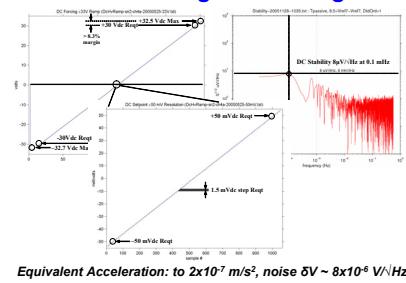
AC Sensing Performance



AC Forcing Performance



DC Forcing and Nulling



Results and Lessons

- Performance objectives met at low frequency $f < 0.1 \text{ mHz}$.
- Margin exists to locate JFET's to 50cm distance from P/M.
- Test object temperature stability $< 1 \text{ mK}/\sqrt{\text{Hz}}$ is paramount.
- Parasitic thermocouple effects call for $10 \text{ mK}/\sqrt{\text{Hz}}$ for wires
- 1-g suspended proof-mass needed for full characterization.

Conclusions

- Combined electrostatic sensing and forcing for GRS can be made to work, but, margins are $\sim 2x$, not $\sim 10x$.
- 6-dof sensing + 5-dof control drives design complexity.
- With segmented electrodes, $f < 0.1 \text{ mHz}$ performance is ultimately limited by voltage reference stability.